(3) Wave reflection and transmission through and over sloping structures and beneath vertical wave screens is also found in Part VI-5-2.

c. Interaction with adjacent beaches.

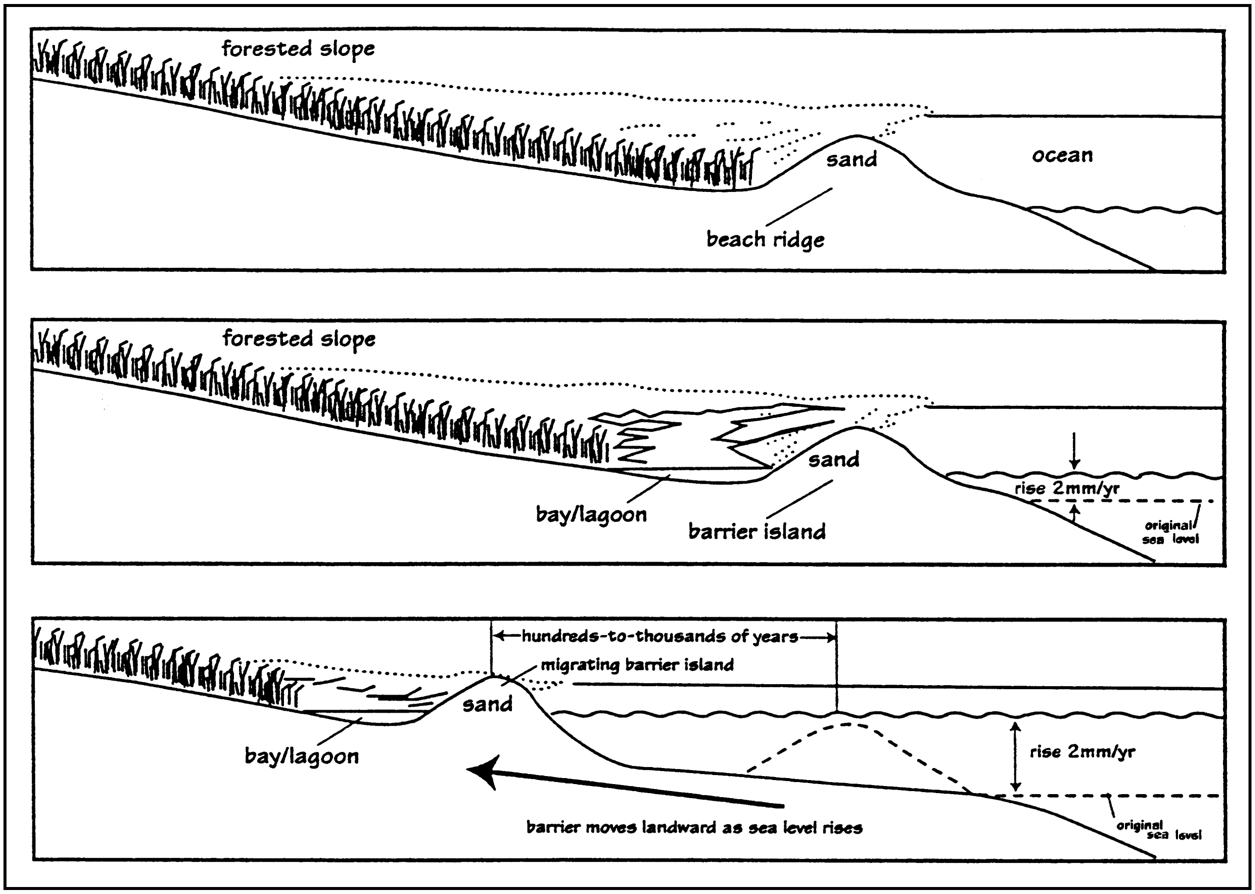
There is a common perception that "… seawalls increase erosion and destroy the beach." The limited available evidence is examined in this section. The term seawall herein means any type of coastal armoring that hardens the shoreline to a fixed position, hence, also applies to bulkheads and revetments.

(1) Background. Concern with how seawalls interact with adjacent beaches can be traced to events in the 1960s and coastal geology studies on the origins and movements of barrier islands (Hoyt 1967). Barrier islands are one of the 11 types of land/water interfaces on earth (Shepard 1976). Barrier beach systems make up about 35 percent of the United States coast stretching from Maine to Texas. They protect the bays and estuaries that lie behind them from direct wave attack, but are dynamic systems with sand volumes that depend on changing ocean conditions, sand supplies, and control boundaries that define the volume.

(a) As depicted schematically in Figure V-3-9a (adapted from Dolan and Lins 1987), barrier islands are commonly perceived to migrate landward with constant volume as sea level rise continues. Storm surge with high waves produce sand overwash into the back bay. The barrier is said to roll over itself, shoreline movement is termed recession, and no volume change means no coastal erosion. Some scientific evidence disputes the rollover model. Leatherman (1988) used shoreline position data to show that tidal inlet formation processes dominate and move far greater sediment quantities over the long term. The migration model also requires the moving sand volume to overlay continuous, basal peat layer from the muds and plants in the lagoon. Stratigraphic evidence contradicts this important aspect along the East Coast of the United States (Oertel et al. 1992). Using the Bruun (1962) rule, a 1-2 mm/year rise in sea level translates to about 0.05-0.2m/year shoreline retreat rate. These are relatively small changes in shoreline position and herein labeled as those at geologic time scales. See Part IV-2-9 for a full discussion of marine depositional coasts and barriers.

(b) When man enters the picture by constructing a road on the shore, he establishes a fixed reference line. The shoreline position relative to the road decreases in time as depicted in Figure V-3-9b. Once development has been permitted, continued erosion may threaten man's artifacts (roads, buildings, bridges, etc.) and some type of shore protection may be undertaken such as seawall construction. These structures are not intended to protect the beach, but areas landward from the beach. Armoring provides a nonmoving reference point on the beach to make the existing, historic erosion more noticeable. Few argue that the road alone is "…destroying the beach", but this same logic is applied by some when a revetment or seawall is present on an eroding shoreline and the dry beach width is reduced each year in front of the hardened shoreline (Pilkey and Wright 1988). Eventually, the ocean will reach the seawall (and road) and the dry beach will be gone.

(c) As also depicted in Figure V-3-9b, a seawall traps sediment behind the structure, reduces overwash and fixes the shoreline position. Continued erosional stress over time acts to deepen the water depth at the structure that is of concern for structural design. The trapped sediment formerly in the dune, bluff or cliff) is removed from that available to contribute to subaqueous bar building during storms. This trapped material is also prevented from contributing to the longshore sediment transport processes along the coast and may alter the sediment budget. The volume trapped relative to that naturally active in the cross-shore profile will be discussed further in the following paragraphs.



a. Barrier island migration at geologic time scales

Figure V-3-9. Time scales for shoreline movements (Continued)

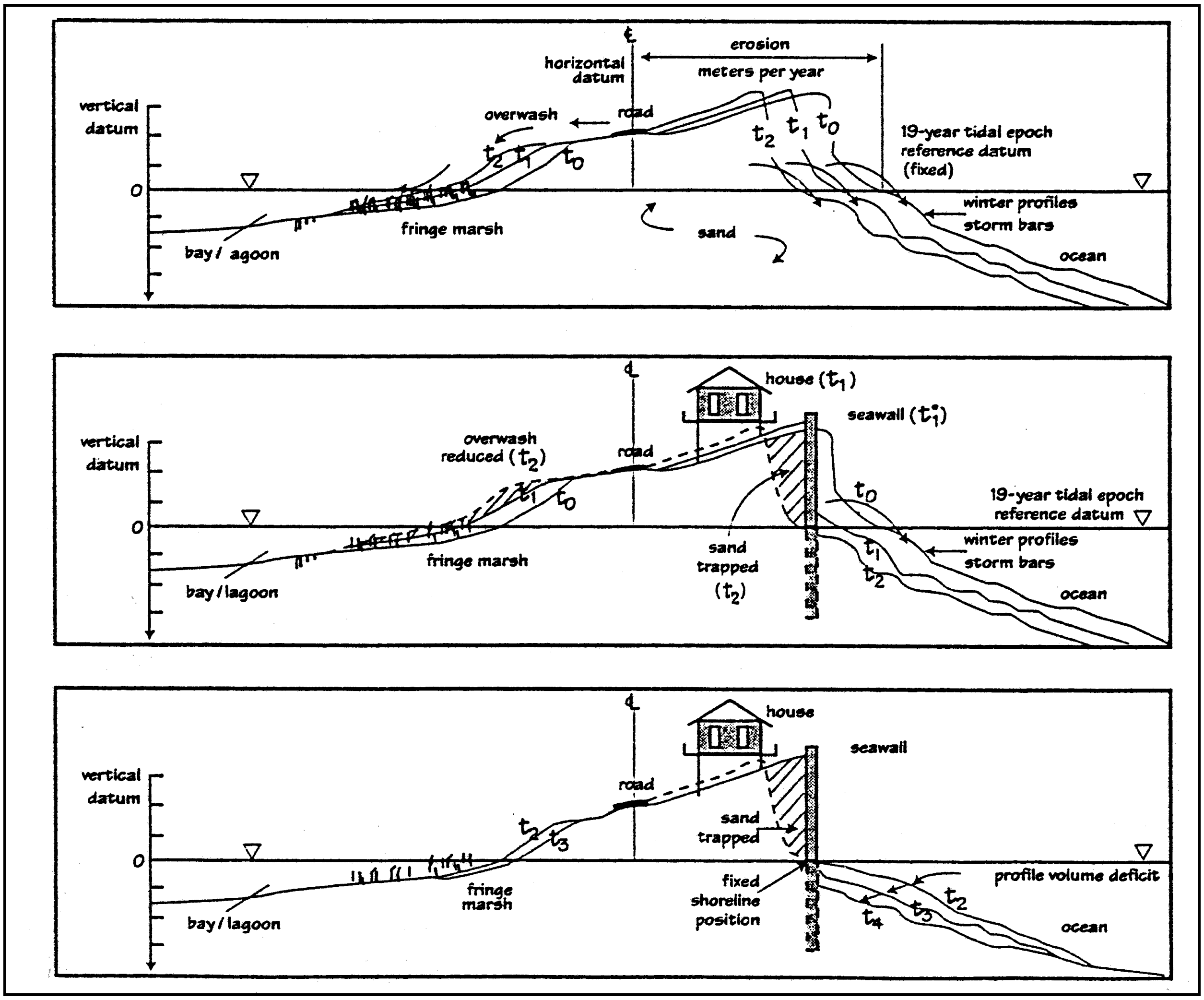
(d) Natural erosion processes (wave-induced, sediment imbalances) plus anthropogenic induced erosion produce larger erosion rates than sea level rise (Komar et al. 1991). These are herein labeled as those at engineering time scales. The degree to which coastal armoring affects the adjacent beach has been the focus of some research effort.

(2) Literature review.

(a) Common concerns. Dean (1987) critically examined nine commonly expressed concerns about seawalls and adjacent beaches as summarized in Table V-3-3. Use was made of conservation of sediment mass, laboratory and field data, and the theory of sediment transport. Conclusions from this analysis were (numbers coincide with Table V-3-4) as follows:

<u>*Concerns Probably False (or Unknown)*</u>

- profile steepening (6)
- delayed beach recovery after storms (5)
- increased longshore transport (8)



b. Coastal erosion at engineering time scales

Figure V-3-9. (Concluded)

- sand transport far offshore (9)

- increase in long-term, average erosion rate (3)

Concerns Probably True

- frontal effects (toe, scour, depth increase) (1)

- end-wall effects (flanking) (1)

- blockage of littoral drift when projecting into surf zone (groin effect) (4)

- beach width fronting armor likely to diminish (2)

Table V-3-3
Assessment of Commonly Expressed Concerns Related to Coastal Armoring (Dean 1987)

No.	Concern	Assessment	
1	Coastal armoring placed in an area of existing erosional stress causes increased erosional stress on the beaches adjacent to the armoring.	True	By preventing the upland from eroding, the beaches adjacent to the armoring share a greater portion of the same total erosional stress.
2	Coastal armoring placed in an area of existing erosional stress will cause the beaches fronting the armoring to diminish.	True	Coastal armoring is designed to protect the upland, but does not prevent erosion of the beach profile waterward of the armoring. Thus, an eroding beach will continue to erode. If the armoring had not been placed, the width of the beach would have remained approximately the same, but with increasing time, would have been located progressively landward (see 2b).
2a	Beaches on eroding coastlines will diminish in front of fixed dune positions.	True	An eroding beach continues to erode relative to a fixed dune position. The width of the beach must diminish if the shoreline is eroding (Figure 1).
2b	Natural beaches on retreating barriers maintain the same beach width.	True	Relative to a retreating duneline, a shoreline eroding at the same rate results in a stable beach width.
3	Coastal armoring causes an acceleration of beach erosion seaward of the armoring.	Probably False	No known data or physical arguments support this concern.
4	An isolated coastal armoring can accelerate downdrift erosion.	True	If an isolated structure is armored on an eroding beach, the structure will eventually protude into the active beach zone and will act to some degree as a groin, interrupting longshore sediment transport and thereby causing downdrift erosion.
5	Coastal armoring results in a greatly delayed poststorm recovery.	Probably False	No known data or physical arguments support this concern.
6	Coastal armoring causes the beach profile to steepen dramatically.	Probably False	No known data or physical arguments support this concern.
6a	Coastal armoring destroys foreshore bar and trough features.	Probably False	No known data or physical arguments support this concern.
7	Coastal armoring placed well-back from a stable beach is detrimental to the beach and serves no useful purpose.	False	In order to have any substantial effects to the beaches, the armoring must be acted upon by the waves and beaches. Moreover, armoring set well-back from the normally active shore zone can provide “insurance” for upland structures against severe storms.
8	Seawalls increase the longshore sediment transport.	Unknown	No known data exists, physical arguments can support or discredit this concern. Needs research.
9	Seawalls cause sand transport a far distance offshore.	Probably False	No known data or physical arguments support this concern.
10	Other		

Kraus (1988) reviewed over 100 references (laboratory, field, theory, and conceptual studies) to make a thorough examination of the literature. This review and seven companion papers are presented in Kraus and Pilkey (eds. 1988). An updated literature review is found in Kraus and McDougal (1996) who examined 40 additional papers. In general, these extensive literature reviews agreed with Dean (1987) regarding which concerns were probably false and which many are true. The interested reader should consult these references for all the details.

(b) Definitions. The natural, background shoreline erosion rate, P_N and the rate *after* human activities P_A can define a coastal erosion ratio, R_P

$$R_p(x,t) = \frac{P_A}{P_N} \tag{V-3-3}$$

where the subscript R_p means shoreline position is used to define R. If profile data are available, then actual, coastal erosion volume could be employed to find a volume ratio, R_V as

$$R_v(x,t) = \frac{V_A}{V_N} \tag{V-3-4}$$

- where V_N is the natural erosion (volume loss) rate and V_A is the volume loss rate after construction of roads, seawalls, etc. at a given location. Clearly, if R_v (or R_p) is proven greater than unity under similar climatological conditions, then we may conclude that armoring has increased the natural, historical conditions at the site. The level of impact (if any) on the frontal and laterally adjacent beaches (1 percent, 5 percent, 10 percent, 50 percent, etc.) needs quantification. Pilkey and Wright (1988) use the terms passive and active erosion of the beach to distinguish between the perceived versus real natural and manmade causes, respectively.

- The volume of sediment trapped behind a seawall depends upon its position on the beach, crest elevation and length. Weggel (1988) defined six types of seawalls depending on their location on the beach and water depth at the toe. At one extreme (type 1) the wall is located landward of the limit of storm wave runup to have zero impact. At the other extreme (type 6) walls are located seaward of the normal breaker line. Types 2-5 lie in between and are said to have increasing effects on coastal sediment processes as the type number increases. Storm surges can create all six type conditions during a single storm event. Coastal erosion may also gradually alter the types.

- Dean (1987) postulated that the sediment trapped behind the wall resulted in an excess erosional stress to produce toe scour and excess erosion on unprotected adjacent property.

(c) Frontal impacts. Beach profile change, toe scour during storms and nearshore bar differences have been attributed to seawalls. Conventional wisdom has been that these impacts were due to wave reflection. Kraus and McDougal (1996) studied the field results by Griggs et al. (1997); laboratory work by Barnett and Wang (1998) and Moody and Madsen (1995) and their own research in the SUPERTANK (large scale) seawall tests (McDougal, Kraus, and Ajiwibowo 1996) to conclude that reflection is not a significant factor in profile change or toe scour. In the field, toe scour is more dependent on local, sediment transport gradients and the return of overtopping water (through permeable revetments or beneath walls) than a result of direct, cross-section wave action. Their conclusions also negate the common perception that sloping and permeable surfaces produce less effects than vertical, impermeable walls. Scour and scour protection is covered in detail in Part VI-5-6.

(d) Impacts on laterally adjacent beach. Perhaps the key environmental concern is how a seawall affects a neighbor beach with no armoring. Does the wall create end-of-wall or flanking effects, i.e., R (x,t) greater than unity? Two studies are often cited to demonstrate flanking effects. Walton and Sensabaugh (1979) provide posthurricane Eloise field observations (14 data points) of additional bluff (contour) recession adjacent to seawalls in Florida. McDougal, Sturtevant, and Komar (1987) and Komar and McDougal (1988) present small scale, equilibrium beach, laboratory measurements (nine data points) for 7-14-cm waves at 1.1-sec periods normal to a median grain-size, sandy beach. The 23 data points are then combined to demonstrate the excess flanking erosion. The extent and length of the excess erosion is related to seawall length and is explained in terms of the seawall denying sand to the littoral system (e.g., Dean 1987).

- However, other mechanisms may be responsible. If the seawall extends seaward, it may act like a groin to cause downdrift impacts. Tait and Griggs (1991) measured an area of lowered beach profile extending 150 m downcoast at Site No. 4 in California. They proved that the upcoast end of the wall produced sand impoundment or a groin effect. Toue and Wang (1990) conducted laboratory experiments with waves attacking walled and nonwalled beaches at angles and concluded that downdrift impacts were a groin effect.

- Plant (1990) and Plant and Griggs (1992) observed rip currents at interior sections and at the ends of armored sections. These rip currents were attributed to wave overtopping, return flows and elevated, beach water tables during storms. McDougal, Sturtevant, and Komar (1987) also observed rip currents in their model tests previously described and from field evidence in Oregon. They concluded that this mechanism may be more responsible for end-of-wall, flanking effects than the sand trapping theory of Dean (1987).

- Griggs et al. (1997) discuss eight full years of field monitoring including the intense winter storm of January 1995. This storm did not produce end scour on the control beach at Site No. 4. They concluded from a comparison of summer and winter beach profiles at beaches with seawalls and on adjacent, control beaches, that no significant long-term effects were revealed.

- Basco et al. (1997) summarize the results of 15 years of profile survey data with 8-9 years taken before seawall construction at Sandbridge, Virginia, on the Atlantic Ocean. The shoreline has been eroding on average 2m/year (Everts, Battley, and Gibson 1983) long before wall construction began. One part of the study used five years of monthly and poststorm profile data at 28 locations (62 percent walled; 38 percent nonwalled) of the 7,670 m study reach. They concluded that the volume erosion rate was not higher in front of seawalls. However, seasonal variability of sand volume was slightly greater in front of the walled locations. Winter waves drag more sand offshore in front of walls, but summer swell waves pile more sand up against walls in beach rebuilding. Walled sections recovered about the same time as nonwalled beaches for both seasonal transitions (winter to summer) and following erosional storm events. These results were for a weighted average of total sand volume (subaerial) in front of the walled section and seaward of a partition for the nonwalled beach sections.

- At individual profile locations adjacent to walls, using the full 15 years of data, R_v values varied considerably. The evidence for any long-term, end-of-wall effects were considered inclusive for Sandbridge beach. There was never evidence of flanking effects after storms on adjacent beaches (Basco et al. 1997). This study continues. In general, Basco et al. (1997) have confirmed all the conclusions of Dean (1987), Kraus (1988) and Kraus and McDougal (1996) except the end-wall, flanking effect.

- Natural beaches coexist in front of the rocky cliffs and naturally-hardened shorelines at many locations throughout the world. A major, comprehensive research effort is needed to quantify the effect of sand trapping on frontal and downdrift beaches.

(3) Active volume in the cross-shore profile. Successive cross-shore surveys of the beach profile to closure depth reveal spatial variations in vertical elevation at each location. In the absence of lateral transport, the eroded sections balance the accreted areas, i.e., sediment volume is conserved. The active sediment volume is defined as one-half of the total volume change between two successive surveys. The 12-year, biweekly nearshore bathymetric data set surveyed at the Corps of Engineers Field Research Facility, Duck, North Carolina, has been analyzed to quantify the total active sand volume, its spatial variation across the profile, and its relation to long-term, fair-weather, and storm periods (Ozger 2000). An empirical relationship between storm wave power and active sand volume has been developed for the Duck site. Prestorm morphology and duration of storm surge are possible factors for the scatter in the power versus active sand volume relationship. The maximum value of active sand volume was $140 m^3/m$ (350 cu yd/ft). Different tidal conditions, wave climate and hard bottoms (or reefs) limit the cross-shore movement of sediment. Determinations of the naturally active, sand volume should be made for other sites. Basco and Ozger (2001) summarize the above results and discuss various applications in coastal engineering. The seawall trap ratio, WTR can be defined as:

$$WTR = \frac{\text{Wall Trap Volume}}{\text{Active Sediment Volume}} \tag{V-3-5}$$

to quantify the relative impact of the sand volume removed from the system. Dean (1987) failed to consider the WTR. Weggel (1988) qualitatively addresses the importance of the numerator increasing with type number but also did not consider the significance of the denominator. The spatial distribution of the WTR is also important relative to wall location. At locations with seawalls where the WTR is small, annual mitigation may be economic.

(4) Sand rights and mitigation. A few states have adopted sand mitigation polices and procedures to permit seawall construction and maintain a healthy beach. The idea is to annually replace the beach materials trapped behind the structure with a volume calculated by some formula. The methodology in Florida has both on offshore and longshore transport components which require knowledge of the annual erosion rate and net, longshore transport rate, respectively (Terchunain 1988). Sarb and Ewing (1996) present formulas for cliff and bluff erosion impacted by seawall construction in California. These formulas attempt to deterministically estimate the wall trap volume (numerator) but do not consider the active sediment volume (denominator) in Equation V-3-5. The relative volume trapped is unknown. Field research efforts to date have yet to confirm the trapping theory of Dean (1987). The reason may be that the trapped volume is only a small percentage of the total, active sand volume in the profile. The WTR is near zero so that downdrift impacts are minimal and lost in the data scatter. See also Part III-5-13 for discussion of measures to manage human influence on sediment supply. Who owns the sediments on eroding shorelines, the local property owners or downdrift interests, is a legal question facing society. The subject of sand rights (Magoon 2000) is an extremely complicated issue that may require settlement by the nation's courts.

V-3-3. Beach Stabilization Structures

a. Naturally stable shorelines. Part IV-2 classifies coasts and their morphology. Marine depositional coasts with barriers and beaches are one of the most widely distributed geomorphic forms around the world. (Part IV-2-9, 10). They form a flexible buffer zone between land and sea. The subaerial beach has two major zones. The foreshore extends from the low-water line to the limit of wave uprush at high water. At this point, the backshore extends to the normal landward limit of storm wave effects. This landward limit is usually marked by a foredune, cliff, structure, or seaward extent of permanent vegetation. The backshore is only affected during storms when surges and high waves transport backshore sediments. This exposed, subaerial beach definition is accepted by the general public. Some authors include the surf zone and bars out to closure depth, i.e., the subaqueous part of the beach, because both parts, subaerial and subaqueous, exchange sediment. Beaches may stretch for hundreds of kilometers or others, called pocket beaches, are restricted by headlands and are only tens of meters in length. Figure IV-3-31 schematically summarizes factors controlling morphodynamics along a range of coastal environments extending from rocky, to noncohesive sediments to cohesive shorelines.

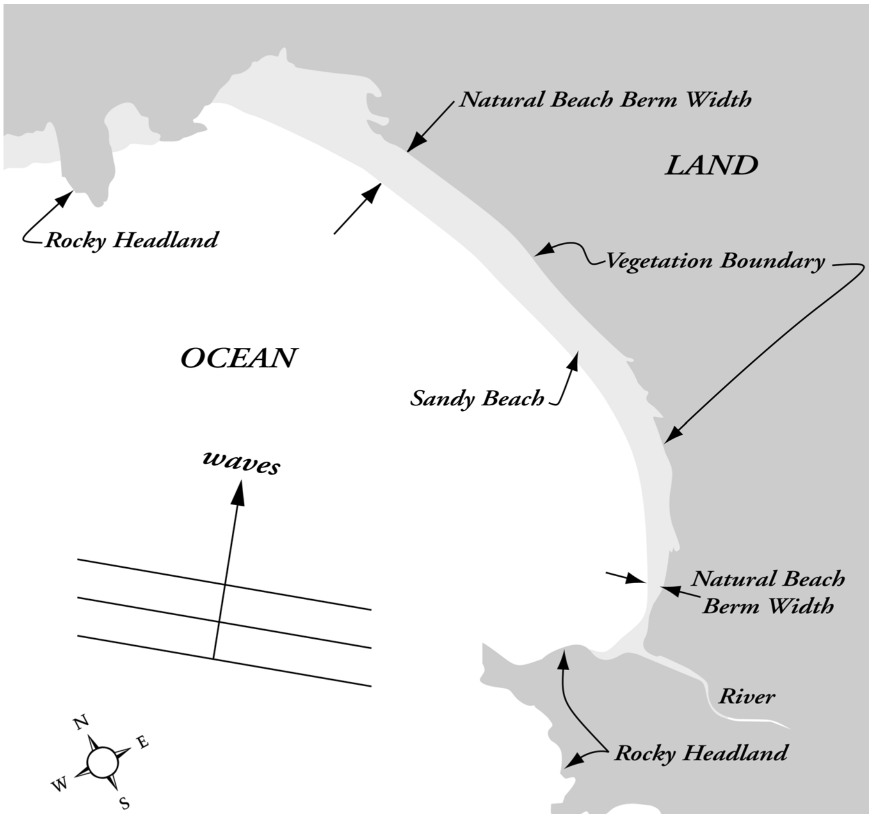
(1) Many beaches are naturally stable. In general, wide beaches are exposed to more severe wave conditions at that location, but the relationship between beach width (or section volume) and storm energy for naturally stable shorelines has yet to be determined. Figure V-3-10a displays a stable, pocket beach on Bruny Island, Tasmania, Australia, where beach width increases along the more exposed section of coast (from Silvester and Hsu 1993). The protected reach behind the headland is much narrower than that receiving a direct attack by large waves during storms. The dark area is vegetation and landward limit of the backshore, subject to normal storm wave effects. If this photo were taken at high tide, a minimum beach width for a stable shoreline could be determined.

(2) This concept of a minimum beach width (or volume) is schematically illustrated in Figure V-3-10b. The volume of sediment present protects the uplands (foredune, cliff, structure, or vegetation) from damage under normal or average storm conditions. The landward boundary of the backshore is a reference baseline for shore protection. On eroding beaches, the backshore may be missing, and the high-water uprush may impinge directly on cliffs or structures. Both natural and anthropogenic agents may cause the erosion. But a minimum, beach width is still necessary for natural shore protection at the eroding site.

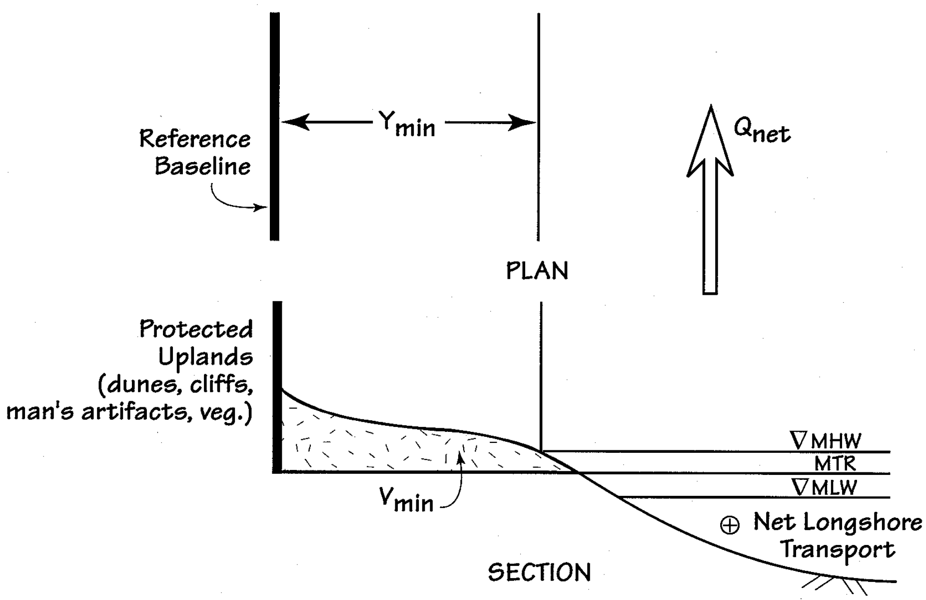
b. Minimum dry beach width. Professor Richard Silvester in an article on the stabilization of sedimentary coastlines (Silvester 1960) wrote:

> "…to allow for storm-cycles and the short-term reversals of drift, a sufficient width of beach should be allowed as working capital on which the sea can operate. Once the coast has been stabilized, by preventing the net movement of sediment, no long-term erosion need be anticipated and the 'active' beach width can be minimized." (p. 469)

(1) As illustrated in Figure V-3-11a,b, for both naturally open beaches and pocket beaches between headlands, the minimum, dry beach width, Y_{min} is defined as the horizontal distance between the mean highwater (mhw) shoreline and the landward boundary or base (reference) line. The mhw shoreline is employed because it is the common, land/water boundary shoreline on maps; it is more readily identified from aerial photos; and it is a more conservative, minimum width (and volume) for shore protection. It is the minimum, dry beach width required to protect the foredune, cliff, structure, or vegetation behind the baseline from normal storm conditions. The beach does the work, and it's resilience and recovery are critical for long-term shore protection.



a. Aerial view (schematic from photograph) of Cloudy Bay, Bruny Island, Tasmania, Australia, showing greater natural beach berm width along the more exposed section of coast (adapted from cover photograph and Figure 3-21 in Silvester and Hsu (1993))



b. Schematic of minimum dry beach width, Y_{min}

Figure V-3-10. Naturally stable shorelines with beach width dependent on stormwave energy (from Silvester and Hsu 1993)

(2) Normal storm wave conditions are expected once every two years or maybe every year. More intense, less frequent storms will reach the foredune, cliffs, structure or vegetation line. Beach stabilization structures can provide upland protection beyond the baseline for these rarer storm events. At a minimum, these structures should be designed to provide the minimum, dry beach width for shore protection.

(3) Figure V-3-11c,d,e depict the three most common beach erosion mitigation structures, namely headland breakwaters, nearshore breakwaters, and a groin field. And, each schematic displays the minimum, dry beach width, Y_{min} that is required for design. In each case, it is located in the gap area with greatest wave energy. The EST methodology discussed in V-3-1-c can be applied to determine the probability distribution of dry beach widths including the minimum for normal storm conditions. Functional design of these structures based on empirical knowledge is presented in the next sections. Two key factors are the minimum dry beach width (or volume) and the natural, sediment transport processes at the site. Explicit acknowledgment of Y_{min} as design criteria is often missing in coastal engineering design.

c. Headland breakwaters.

(1) Background and definitions. Natural sandy beaches between rocky headlands have been called a variety of names in the literature, related to the curved shape of the bay found at many coasts around the world. Silvester and Hsu (1993) summarize the literature. See also Part III-2-3-i. for a list of references. Because of their geometry, they have been called spiral beaches, crenulate-shaped bays, log-spiral and parabolic-shaped shorelines, headland bay beaches and pocket beaches. Half-Moon Bay in California is a good example as first discussed by Krumbein (1944) and shown as Figure 4.3 in Silvester and Hsu (1993). Many researchers have studied the dynamic processes of this geomorphic feature, but Silvester (1960) was the first to examine their static equilibrium and propose the creation of artificial headland breakwaters as a shore protection structure. Figure V-3-12 presents a sketch of an artificial headland system and beach planform (from EM 1110-2-1617, "Coastal Groins and Nearshore Breakwaters."). Normal wave conditions with a predominant swell direction produce a maximum indentation between two fixed points (breakwater structures) and a fully equilibrated, planform shape. Thus man can mimic nature by building the headland breakwaters and letting nature sculpture the beach with a limiting indentation and shoreline that is stable.

(2) Physical processes. Waves from one persistent, dominant direction, β, diffract around the upcoast headland and refract into the bay. Waves will break at angles to the shoreline causing sediment transport and shoreline shape adjustment (nonequilibrium shape) until a full equilibrium shape is reached. At this stage, waves break simultaneously around the entire periphery, no longshore currents and no littoral drifts occur within the embayment. The tangent section, adjacent to the downdrift headland is exactly parallel to the normal wave crest direction from offshore. Such a bay is said to be in static equilibrium (i.e., it is stable until there is a shift in the dominant wave direction). Minimal amounts of additional sediments enter or leave past the headland boundaries. Bidirectional, dominant, wave impact (swells and storms) and sediment bypassing the headlands are two reasons for littoral drift to continue around the bay. These bays are said to be in dynamic equilibrium and can be predicted within certain tolerances. Only the static equilibrium shapes can be related to wave input. The ability to calculate the static equilibrium shape and maximum indentation are needed for the functional design of headland breakwaters.

(3) Functional design. Early investigators employed a log-spiral curve to fit the planform shape (Yasso 1964; Silvester 1970). In practice it is difficult to apply because the center of the log-spiral does not match the point at which diffraction begins to take place.

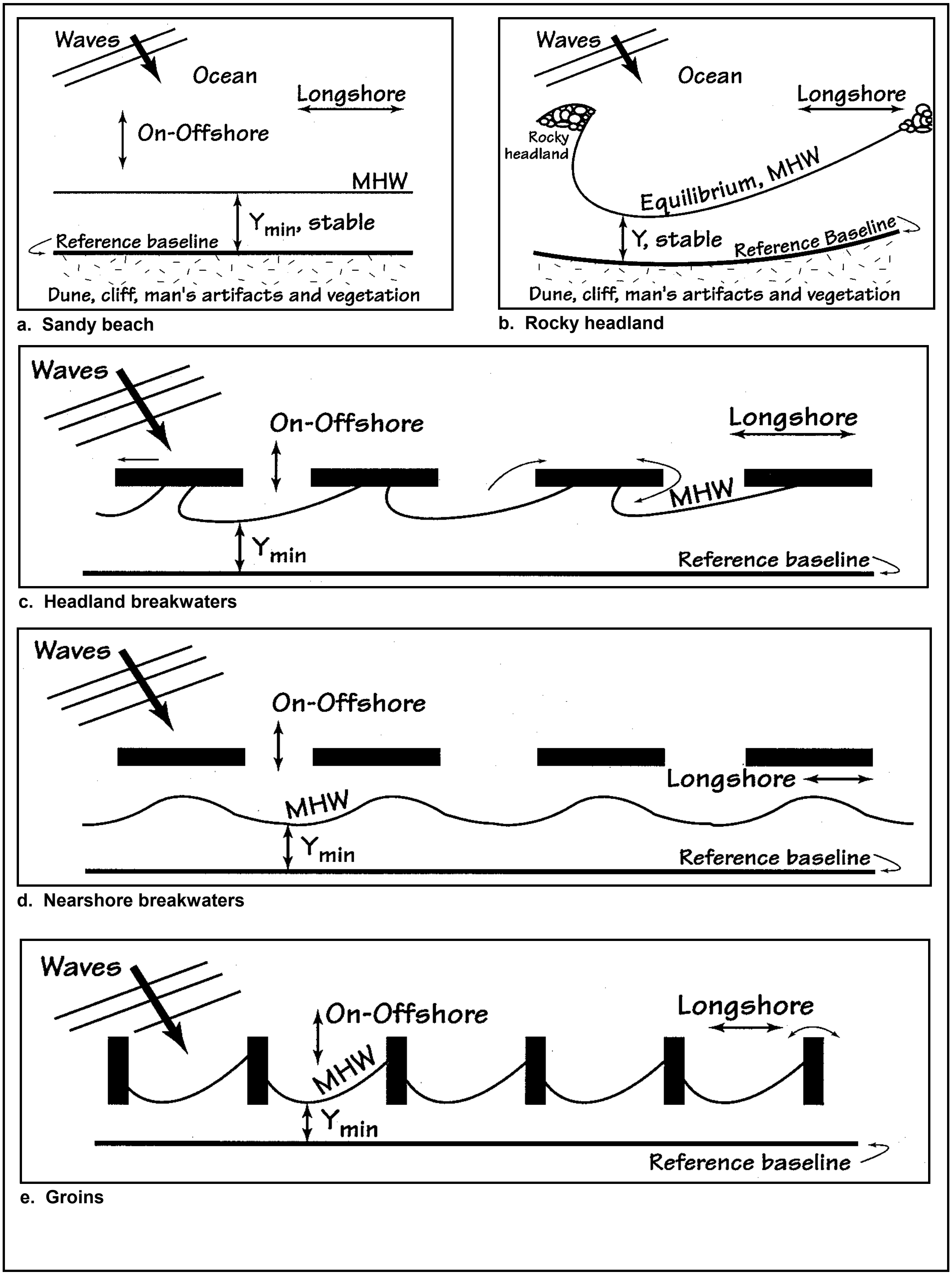


Figure V-3-11. Natural and artificial stable shorelines with minimum dry beach width, Y_{min}

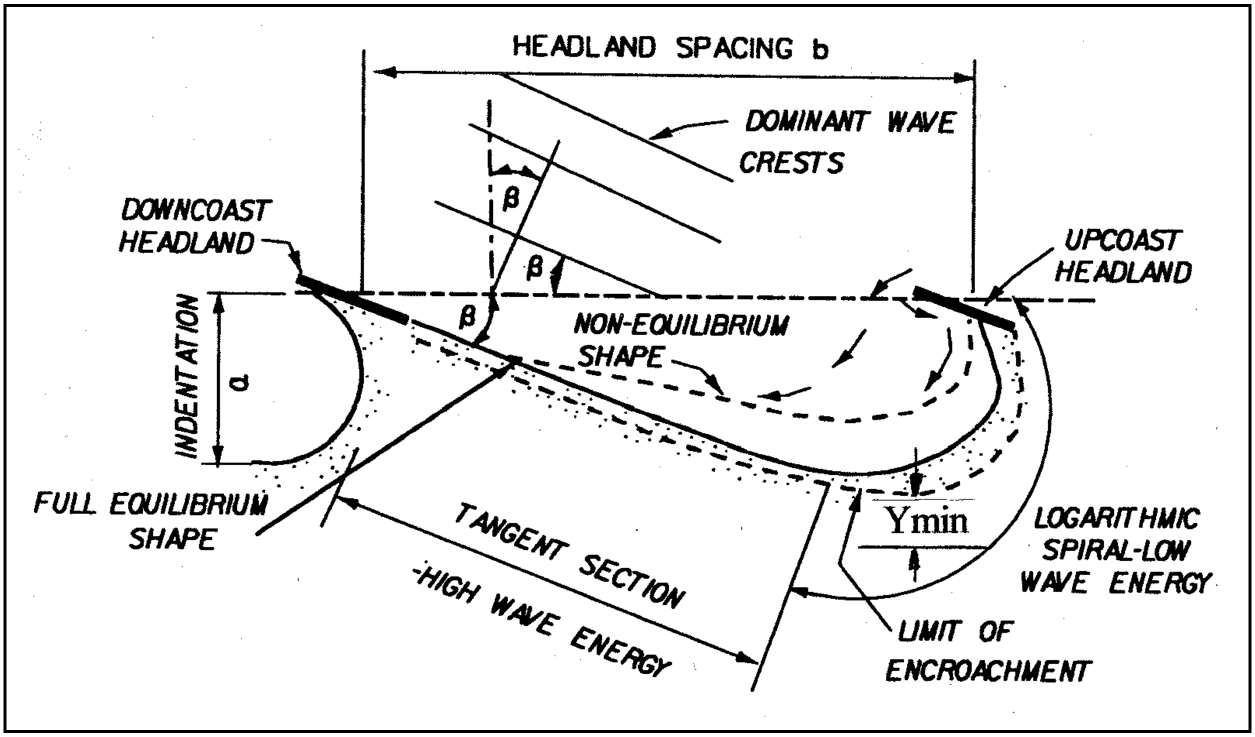


Figure V-3-12. Definition sketch of artificial headland system and beach planform (from EM 1110-2-1617)

(a) Parabolic bay shape. A new empirical approach that uses shoreline data from bays in static equilibrium and physical models has been developed by Hsu, Silvester, and Xia (1987, 1989). It is called a parabolic model because the data has been used to fit a second order polynomial. Figure V-3-13 presents a definition sketch of the four key geometric variables, R, R_o, β and θ, that form the parabolic model. The model center now exactly matches the initial diffraction point. Part III-2-3-i presents complete details including definitions of R, R_o, β and θ; the parabolic model equation (2-24); the three coefficients C_o, C_1, C_2 related to wave angle β in Figure III-2-27 and limitations of the data. An Example Problem III-2-8 is also presented to illustrate an application of the model which assumes one predominant wave direction exists at the site of interest. Many more examples and discussion is found in Silverster and Hsu 1993.

(b) Minimum width for storm protection. As illustrated in Figure V-3-12, storm waves may be from a different direction to cut back the beach and form a new limit of encroachment planform shape. A more detailed definition sketch in perspective and cross section is presented in Figure V-3-14 (adopted from Hardaway, Thomas, and Li 1991). Two nearshore breakwaters together with beach nourishment form the headland breakwater design for shore protection. The following terms are defined:

L_s Length of breakwater structure

L_g Gap distance between adjacent breakwaters

d_s Depth (average) at breakwater below mean water level

e Erosion of shoreline (mhw) from design storm

Y_o Distance of breakwater from original shoreline

Y_g Maximum indentation under normal wave conditions

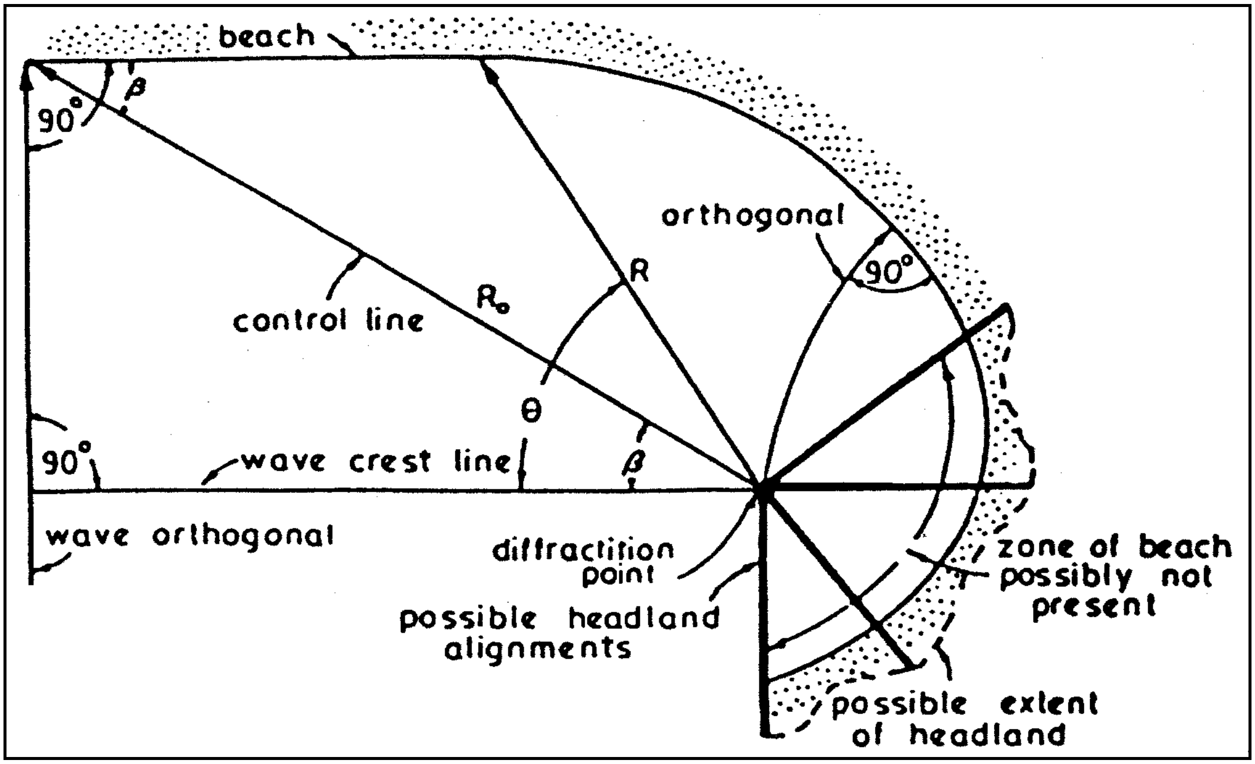


Figure V-3-13. Definition sketch of parabolic model for planform shape

Y	Distance of breakwater from nourished shoreline
Y_{min}	Minimum distance from base (reference) line to mhw shoreline after design storm event
B	Minimum beach width at mhw after nourishment
W	Width of design beach nourishment
Z_s	Backshore elevation at baseline
F_B	Breakwater freeboard, mhw to crest
Q_{net}	Net longshore sediment transport rate
Q_{gross}	Gross longshore sediment transport rate
$Q_{offshore}$	Offshore sediment transport rate for design storm

The planform shape and maximum indentation, Y_g can be estimated by the parabolic shape model previously discussed above. A hyperbolic tangent shape was developed by Moreno and Kraus (1999), which may be more convenient to apply than the parabolic shape.

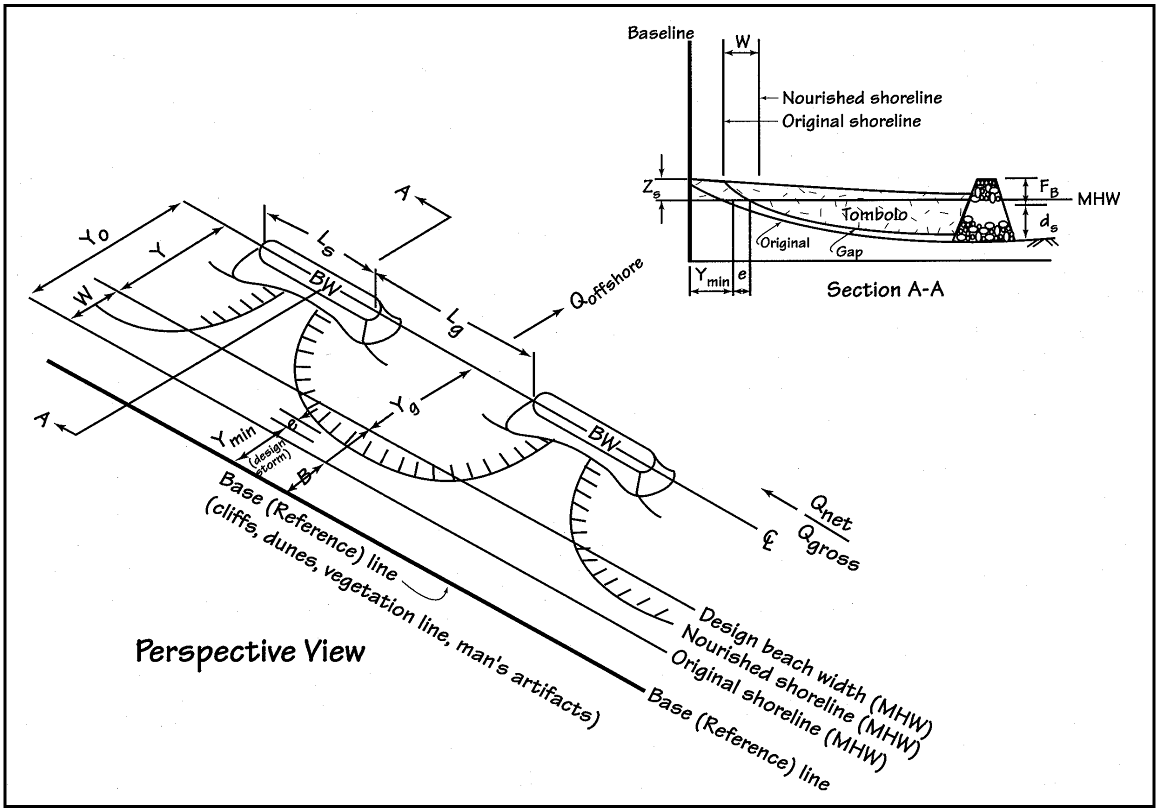


Figure V-3-14. Definition sketch, headland breakwaters

(4) Applications on Chesapeake Bay. Headland breakwater systems have been built along the shoreline of the Chesapeake Bay for shore protection and to maintain recreational beaches. Since 1985, 60 breakwaters at 19 sites have been designed, constructed, monitored and analyzed to learn about their functional performance (Hardaway, Thomas, and Li 1991; Hardaway, Gunn, and Reynolds 1995; Hardaway and Gunn 1991, 1995, 1998, 1999). The design method employs a three-step procedure that accounts for bimodal annual wave climates (annual and storm wave direction) a numerical wave transformation model for near-shore wave refraction and shoaling, and the beach planform shape model for static equilibrium (Silverster and Hsu 1993). System design also includes upland runoff, bank geology, shoreline morphology, sedimentation, and aesthetics. Potential impacts to adjacent shorelines must also be considered and minimized.

Figure V-3-15a displays before and after photos for the Van Dyke project on the James River. The dark area along the shore is vegetation after the new bank was graded to provide sand for beach nourishment as part of the construction. Figure V-3-15b displays 12 nearshore breakwaters at the Luter project site (James River) one year after construction. Note the use of Y-shaped breakwaters to refine the shape of the planform beach. Moving the breakwater ends further offshore changes the diffraction point to provide the desired planform beach shape. Short breakwaters at both ends pin the downdrift beach. Experience since 1991 indicates that on the Chesapeake Bay, the ratio of Y_g/L_g is about 1.7 for stable, equilibrium-shaped beaches. As illustrated in Figure V-3-16, at the Murphy project site (Potomac River) the present shore is still eroding and will require several years to reach the predicted embayment shoreline shape. Hardaway, Thomas, and Li 1991 present minimum design parameters for medium wave energy shorelines (average fetch 1-5 nautical

a. Van Dyke Project

b. Luter Project

Figure V-3-15. Headland breakwater projects on the James River estuary, Chesapeake Bay (from Hardaway and Gunn 1999)

miles) that include guidelines for distance B (Figure V-3-14) related to storm surge and wave conditions. Much more research is needed to relate Y_{min} to design storm conditions for the functional design of headland breakwater systems. The next section discusses analytical methods to estimate Y_{min} during storm conditions.

d. Nearshore breakwaters.

(1) Background and definitions. Nearshore breakwaters are detached, generally shore-parallel structures that reduce the amount of wave energy reaching a protected area. They are similar to natural bars, reefs or nearshore islands that dissipate wave energy. The reduction in wave energy slows the littoral drift, produces sediment deposition and a shoreline bulge or salient feature in the sheltered area behind the breakwater. Some longshore sediment transport may continue along the coast behind the nearshore breakwater.

(a) Figure V-3-17 displays a salient behind a single breakwater and a multiple breakwater system with both salient and a tombolo when the shoreline is attached to the breakwater. The tombolo may occur naturally or be forced during construction to produce a headland breakwater as discussed in the previous section. The tombolo blocks normal, longshore sediment transport behind the structure. Daily tidal variations may expose a tombolo at low tide while only a salient feature is visible at high tide as occurs at the Winthrop Beach, Massachusetts, nearshore breakwaters constructed in 1935 (Dally and Pope 1986). Figure V-3-18 displays the single 610 m long, rubble-mound breakwater at Santa Monica, California, and salient feature (circa 1967). Periodic dredging is needed to prevent tombolo formation. The multiple, nearshore breakwater system at Presque Isle, Pennsylvania, is shown in Figure V-3-19 (Fall 1992). Fifty-five breakwaters were built in 1989-1992 to protect 8.3 km (13.8 miles) of Lake Erie shoreline (Mohr 1994).

(b) In general, the primary objectives of a nearshore breakwater system are to:

- Increase the fill life (longevity) of a beach-fill project.

- Provide protection to upland areas from storm damage.

- Provide a wide beach for recreation.

- Create or stabilize wetland areas.

(c) In addition, adverse effects on downdrift beaches should be minimized by consideration of the impact on longshore sediment transport.

(d) Numerous variations of breakwater types exist. Here, the focus is on detached, offshore breakwaters not connected to shore by any type of sand-holding structure. They may be low-crested to permit increased wave transmission and lower construction costs. They also may be reef-type breakwaters constructed of homogeneous stone size as opposed to the traditional, multilayer, cross-section design. Headland breakwaters (natural or constructed tombolos) are discussed (Part V-3-3). Another type of shore-parallel, offshore structure is called the submerged sill or perched beach and is discussed in (Part V-3-3). Additional